NNN05

ENGINEERING OF LARGE & DEEP ROCK CAVERNS FOR PHYSICS RESEARCH
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Pierre Duffaut, CFMR
French Committee on Rock Mechanics
ENGINEERING OF LARGE & DEEP CAVERNS FOR PHYSICS RESEARCH

1 - examples of large caverns in France and worldwide
   (shape of their sections and practice of their support)
3 - theory of the hole and stress control
4 - some conclusions for a billion litres cavern
   (that is a cubic hectometre = $100^3 = 10^6 = 1\,000\,000\,m^3$)
examples of large caverns in France and worldwide shape of their sections and practice of their support)
CHORANCHE natural cave, Vercors (Isère)
about 60 m wide
## KNOWN NATURAL CAVES

<table>
<thead>
<tr>
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<th>width</th>
<th>height</th>
<th>length</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choranche (F-38)</td>
<td>60</td>
<td>20</td>
<td>80</td>
<td>rather flat roof massive limestone, $H$ 100 m</td>
</tr>
<tr>
<td>Poudrey (F-39)</td>
<td>100</td>
<td>37</td>
<td>130</td>
<td>flat roof</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>limestone stratum, $e$ 20 m</td>
</tr>
<tr>
<td>la Verna (F-65)</td>
<td>230</td>
<td>180</td>
<td>270</td>
<td>arched roof</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>massive limestone, $H$ 100 m</td>
</tr>
<tr>
<td>Sarawak (Malaysia)</td>
<td>415</td>
<td>100</td>
<td>600</td>
<td>lightly arched roof</td>
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<tr>
<td></td>
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<td>rather small cover about 100 m</td>
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### UNDERGROUND MINE CAVERNS

<table>
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<tr>
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<th>Remarks</th>
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</thead>
<tbody>
<tr>
<td>Anjou (F- 49)</td>
<td>25</td>
<td>80</td>
<td>100</td>
<td>large vertical rooms, slate along schistosity</td>
</tr>
<tr>
<td>May sur Orne (F- 14)</td>
<td>30</td>
<td>5</td>
<td>100</td>
<td>large rooms along strata (45° and 80°)</td>
</tr>
<tr>
<td>Tytyri (Finland)</td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>large tetrahedral rooms</td>
</tr>
</tbody>
</table>
# UNDERGROUND POWER PLANTS

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<th>Remarks</th>
</tr>
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<tbody>
<tr>
<td><strong>hydro</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Le Sautet (F 38)</td>
<td>35</td>
<td>20</td>
<td>35</td>
<td>half-circle roof, 1933</td>
</tr>
<tr>
<td>Poatina (Australia)</td>
<td>13,7</td>
<td>16</td>
<td>50</td>
<td>trapezium roof, stress control slots</td>
</tr>
<tr>
<td>Grandmaison (F 38)</td>
<td>17</td>
<td>39</td>
<td>162</td>
<td>key hole, horizontal anchors</td>
</tr>
<tr>
<td>Cirata (Indonesia)</td>
<td>35</td>
<td>49,5</td>
<td>253</td>
<td>ovoid, radial anchors</td>
</tr>
<tr>
<td><strong>nuclear</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chooz (F- 08)</td>
<td>18,5</td>
<td>37,5</td>
<td>41</td>
<td>2 caverns linked by many galleries (declassified 1992)</td>
</tr>
</tbody>
</table>
Typical underground power plant cavern

courtesy ITA

mushroom shape
GRAND’MAISON underground power plant
1800 MW
(Isère)
surface plant
6 Pelton runners

main plant
4 Francis runners
PORĄBKA JAR

underground power plant (POLAND)

ovoid section

support by rock bolts all around
### VARIOUS + hydrocarbon storage

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<th>Remarks</th>
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<tbody>
<tr>
<td>Banque de France (Paris)</td>
<td>100</td>
<td>3,5</td>
<td>108</td>
<td>inside a limestone formation, flat room, 700 concrete pillars</td>
</tr>
<tr>
<td>Gjøvik skating rink (Norway)</td>
<td>61</td>
<td>25</td>
<td>91</td>
<td>arched roof, widest unsupported civil cavern</td>
</tr>
<tr>
<td>CERN LEP (CH Geneva)</td>
<td>21,4</td>
<td>22</td>
<td>85</td>
<td>horseshoe, half circle roof (wider spans now for LHC)</td>
</tr>
</tbody>
</table>

### oil and gas storage caverns

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</tr>
</thead>
<tbody>
<tr>
<td>Donges (F- 44)</td>
<td>16,5</td>
<td>22</td>
<td>115</td>
<td>two parallel rooms, gneiss</td>
</tr>
<tr>
<td>Porvoo (Finland)</td>
<td>20,5</td>
<td>34</td>
<td>500</td>
<td>27 rooms, gneiss</td>
</tr>
<tr>
<td>Manosque (F- 05)</td>
<td>80</td>
<td>350</td>
<td>600</td>
<td>35 very large caverns, rock salt</td>
</tr>
</tbody>
</table>
since 1924

safe room, 100 x 106 m square, 600 concrete pillars

25 m below ground, 15 m below water table
Gjøvik Olympic Mountain Hall (Norway)

61 m

widest civil engineering cavern under 30 m granite

courtesy ITA
swimming pool in Helsinki (Finland) excavated in granite

15 x 10 m GRANITE

courtesy ITA
CERN, from LEP to LHC

modification of points 1 & 5 : new caverns and shafts at point 1

small ring SPS / large ring LEP, now turned to LHC
CAVERNS
hydro and thermo power plants
mushroom

POATINA Australia
TAKAMAKA Réunion
destressing slots

PORVUO
Finland
evolution of caverns for fuel storage

ovoid
SOLUTION CAVERNS IN ROCK SALT FOR OIL & GAS STORAGE

1 Tersanne
2 Etrez
7 Eminence (USA)
10 Manosque
11 Hauterives
12 Salies de Béarn

courtesy Pierre Berest
STORAGE CAVERN

8 x 12 m

in cretaceous chalk

shallow rock cover

without any support

flat concrete floor

COURTESY GEOSTOCK
INCHON hydrocarbon storage cavern KOREA
12 x 20 m
PART 2

a recent French textbook (2000-2004) collective work signed by CFMR French Committee on Rock Mechanics

vol. 1: *Fundamentals* 2000

vol. 2: *Applications* 2004

« Presses de l’Ecole des Mines »
60 Boulevard Saint Michel Paris,
http://www.ensmp.fr/Presses
vol. 1: fundamentals

coordinated by Françoise Homand et Pierre Duffaut

- chapter 1: introduction & presentation of rock mechanics
- chapter 2: rock physics
- chapter 3: mechanical behavior of rocks
- chapter 4: structural description of rock masses
- chapter 5: mechanical behavior of discontinuities
- chapter 6: water in rocks and rock masses
- chapter 7: stresses in rock masses and their measurements
- chapter 8: constitutive laws
- chapter 9: rupture
- chapter 10: thermo-hydro-mechanical couplings
- chapter 11: clay rocks
vol. 2: applications

coordinated by Pierre Duffaut, JL Durville, JP Piguet, JP Sarda

1 rock engineering design
2 mechanics of actions on the rock mass
3 mechanics of underground works
   chapter 18 shafts
   chapter 19 tunnels
   chapter 20 caverns
   chapter 21 underground storage
   chapter 22 storage of radioactive waste
   chapter 23 underground mining
   chapter 24 oil and gas production
   chapter 25 geothermy

4 mechanics of surface problems and works
5 perspectives
the place of GEOLOGY in geotechnics

- miners have to follow their lode, along GEOLOGY
- all underground works are embedded in GEOLOGY
- inside the ground, we are like surgeons (in man body)
- **anatomy**: which materials and structures inside?
- **physiology**: what is moving, water, heat, stress, etc?
- surface **morphology** may give useful clues
- we have to accept the ground at it comes; it is the same with weather, along the Norwegian proverb “no bad weather, only poor clothes”
  ”**no bad ground, only poor engineering**”.

we may have to escape wrong sites and choose right ones,
we may choose right shapes and the best orientation
main scales in rock mechanics

years

1 metre

déformations tectoniques
stockage de déchets radioactifs
génie civil
mine

seconds

1 day

10^{12}s

10^9s

10^6s

10^3s

1s

1ms

μm

mm

m

km

Mm

métabolisme

alterations

fluage

essais de labo

broyage

concassage

essais dynamiques tir

séismes
main structures of rock masses

brickwork
never in Nature

stratified rock mass
bedding + diaclases

only diaclases

igneous rock mass

unique: CUZCO
the twelve corners stone

Inca stone work

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main structures of rock discontinuities

cubical isotropic

tabular & schistose anisotropic

mylonitic fault gouge
2 methods for wide tunnels

SEIKAN Undersea tunnel, JAPAN
CHANNEL Undersea tunnel, F-UK
SEIKAN TUNNEL

Japan

excavated by the so-called GERMAN method, first used at Tronquoy tunnel in France, 1803

designed for 2 standard gauge Shinkansen tracks (yet operated with 2 narrow gauge tracks)

courtesy Goichi FUKUCHI
CHANNEL TUNNEL
France side crossover

19,90 m
RIB in ROCK  
rock reinforcement before excavation

scandinavian utopy 1977

japanese utopy 1995
PART 3

theory of the hole inside a highly stressed medium

& stress control
2D axisymmetric elastic case: stresses around a cylinder (both the stress field $p$ and the medium are isotropic)
ROCK BURSTS & ROCK BOLTS!

ROCK BURSTS AT MONT BLANC TUNNEL

PHOTO BORIE 3440 m from France

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SOUTH AFRICA gold mines

evolution of rock rupture around very deep tunnels (~ 3000 m)

COURTESY Daniel ORTLEPP CSIRO

Pierre Duffaut
elastic behaviour limited by Coulomb law

when the rock strength is too low, a pressure inside the hole may prevent the tangential stress to overpass this strength
THEORY of the HOLE (3)

elasto-plastic behaviour limited by Tresca law

the deformation inside the plastic annulus preserves the elastic zone around from any excess of stress
the worksite which taught me how rock behaves around deep tunnels

LANOUX slates behavior under more than 300 m cover
3 mechanisms of self adaptation to any excess of stress

- crack opening / squeezing of gouge / slip on joints
- rock defects play like built-in safety valves
destressing slots from the tunnel

destressing tunnels excavated before the main one

when they close, the stress vanishes
destressing slots from the tunnel

fortunately, any anisotropy, of rock or of stress, will decrease the number of cuts or tunnels from five or six to one pair

destressing tunnels excavated before the main one
STRAIN CONTROL

upper galleries will limit the stresses around the wide vault below (patent SELMER, Norway)

in addition they may host cable anchorages
some conclusions for a billion litres (megaton) chamber
TINDAYA MONTAÑA
FUERTEVENTURA ISLAND
CANARY PROVINCE, SPAIN

E. CHILLIDA SCULPTURE
CLOSE TO A CUBE 45-50-60 m

• one ACCESS GALLERY towards horizon
• two SHAFTS (towards sun and moon)

ARUP PROJECT, to begin 2007
underground works are unrecognized & underrated

contrary to bridges and other prestigious buildings,
• they are "built" out of view of passers-by,
• they don’t appear in the built landscape,
• for long they did not rely on accurate calculations,
• they do not glorify their owners,
• neither any professionals involved, be architects, engineering bureaus, contractors, and so and so
underground works are unrecognized & underrated

when conditions get tough, the civil engineering community doesn’t understand underground works

only mining people can tackle them
the cheapest and fastest way for a billion litres cavern is **a nuclear explosion**

within a tenth of a second a spherical cavern is formed which will evolve into a kind of chimney and leave a void cylindrical cavern over a melt rock lake filled with collapsed debris

in order to obtain a megaton volume a 100 kiloton bomb would be needed

I don’t think it is yet serious

from Underground nuclear testing in French Polynesia, 1999
conclusions for a billion litres cavern

- multiple caverns would call for very wide spacing
- even so, excavating the next one would be very dangerous for the stability of the first ones
- horizontal caverns are very sensitive to rock & stress anisotropy (one direction only permitted)
- many suppose that granite-like rocks are the best ones
- deformation of schistose rocks, such as Fréjus rocks, could assist destressing before excavation
- a megaton cavern at Fréjus is an impressing challenge
I would like helping you master it

THANK YOU
La Liberté, lightening the MEGATON cavern